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On the Farmer's Radar: Top 10 Tech Trends for Agriculture

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Introduction

Agricultural practice is approaching a threshold moment, where a new wave of technologies will contribute to a revolution in practice that is comparable to the one precipitated by widespread mechanisation. Termed [agriculture 4.0](#), this new revolution will feature the gradual replacement of manual human labour, the pervasion of farm businesses by advanced information technology, and a food supply chain that is more connected than ever before. The following are some examples of technologies that are likely to drive this revolution, and have a profound impact on agricultural practices.

Distributed Ledger Technology

Agriculture, as part of a complex global food supply chain, relies heavily on transactional business operations. Trust and authenticity are therefore central tenets of the system, and both financial and productivity losses occur when the chain of transactions breaks down (e.g. through fraud). Ledgers (originally in books) have been used throughout history as an asset database, recording all aspects of business transactions, particularly finances. Distributed ledgers are an evolution of this system, where such records can be shared across multiple organisations. In the most modern iteration, these are electronic ledgers, where the information within them is encrypted by electronic security protocols such as 'keys' and 'signatures' which control what any person with access to the shared ledger, can do with it. The system takes advantage of 'block chain' technology, which divides transactions into 'blocks' secured with a cryptographic signature. The key advantage of this technology, over all other transactions, is that a ledger is created with each transaction automatically added to the ledger when it is completed. This ledger is then distributed in blocks, which means that any entity wishing to interfere with the process, can never have access to all the pieces of the ledger that they would need to alter at once, ensuring the authenticity of transactions far beyond any existing system. There is no single point of failure, and everyone accessing a ledger can see an identical copy, meaning that any changes made maliciously would have to pass the scrutiny of all the entities who have access to the ledger. An example of this applied to the agriculture supply chain, is the [red meat block chain model](#) proposed for Australian beef farming, and the [proof of concept released by DEFRA for red meat traceability](#) in the UK, although many more exist. Distributed ledger technology can be applied to almost all transactional activity in the food supply chain, enhancing security,

traceability, and integrity.



Smart, Safety and Traceability Techniques

A combination of a high incidence of (highly publicised) food-based health concerns from which trust must be rebuilt, and an increasing demand from consumers, has put supply chain traceability high on the agenda. There is a need for entities at all stages of the food chain to have a strong knowledge and understanding of the range of traceability technologies that are available in order to meet the expectations of their customers. In terms of product identification, the guiding principle of new technologies is the attachment of some form of 'tag' to a product, containing information about it that travels with it through the supply chain all the way to market. This applies equally to a raw cut of meat as it does to the herbs and spices which are used in a ready meal curry. A standard example of a tag is the radio frequency identification (RFID) tag attached to farm animals, which encodes data about the animal which travels with it as it is processed. The focus of development in this area has been the miniaturisation of tags, including the use of advanced materials to create micro/nano electronics which can be attached to a wider range of products. As well as physical approaches, there has also been development in the area of chemical approaches, where chemical tags are used to categorise certain produce, particularly in terms of quality or origin.

A further development is the use of genetic analysis to authenticate the contents of food products, particularly in response to issues of food contamination. Genetic testing has become less expensive, quicker, and more reliable in recent years, allowing it to be applied in far more situations than was previously the case. It is no longer the preserve of specialist labs, and is being incorporated into a growing range of analysis protocols and consumer products. Genetic testing sits alongside chemical and environmental monitoring as measures which have been primarily developed to improve food safety. For example, measures of humidity, temperature, and pollutants are routinely incorporated into processing systems. The development of [advanced materials](#) will likely accelerate the use of these techniques, with

examples such as [nanocapsules for food spoilage indication](#) already in development.

Agriculture will also be heavily influenced by developments in geospatial technologies such as geographic information systems (GIS), remote sensing (RS) and global positioning systems (GPS). All of which will provide more information about the spatial distribution of farming activities, which will (and is) coupled with indicators such as yield, quality, and disease prevalence. This approach will provide indications about the most appropriate activities on a given site, helping farmers to make decisions to diversify/change/optimize their operations, as well as providing information to customers about products linked to the site/area where they were produced, with an implied differentiation based on provenance. All of the advances mentioned incorporate developments in software and hardware to make them useable, including electronic chip readers, management software, data storage/access, and physical infrastructure.

Traceability technologies are also applied to the security of farm animals. For example, [spray markers](#) containing forensically coded microdots have been developed in response to a drastic increase in sheep thefts in the north of England. The microdots contain a unique identification code linked to the farm of origin, and the markers become entangled with the wool fibres and are ingrained in the sheep's fleece, making them virtually impossible to remove. The system also employs an early warning system, which alerts neighbouring farms, abattoirs, police and auction houses. The spray can also be applied to farm vehicles and machinery, another common target for rural thieves.

Precision Agriculture

Precision agriculture comprises a range of technologies which seek to improve the accuracy and efficiency of farming processes. All of the technologies which contribute towards this approach are designed to provide data, which is in turn converted into insights, which then (theoretically) result in better-informed decision making. These decisions can be made in the presence or absence of a human, depending on the nature of the task. This is the basis of automation. Moreover, a system which is able to continually improve the accuracy or efficiency of a task, based on the data it receives, is the basic description of artificial intelligence (AI), which is the natural evolution of automation. The data upon which decisions are made are collected using a range of sensing technologies including environmental sensors, crop sensors, imaging technology (including advanced multi/hyperspectral imaging), equipment sensors (such as those attached to farm machinery), GIS, and the associated networks. Smart crop sensors analyse a huge range of variables pertaining to plant health such as water needs, soil electrical conductivity, ground elevation, organic matter content, soil nitrogen, and pH. Optical sensors, for example, measure light reflectance from the crop, which can then be translated into nitrogen levels. For example, in the past a farmer might have lost a large proportion of a strawberry harvest to unexpected frosts. However, with sensors measuring soil moisture, air temperature and humidity, and notifications sent to a

smartphone, preventative measures can be taken in time. [Asparagus farmers in California](#), have employed the use of smart sensors in conjunction with IoT (Internet of Things) and LoRa (Long Range wireless data communication service) to increase yields whilst reducing water use by 6% and simultaneously doubling yield.

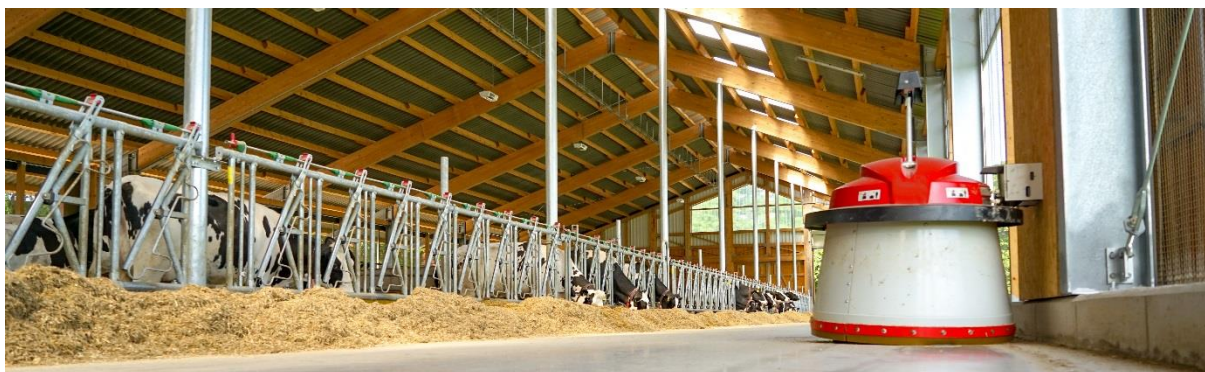
This information can be applied at a variety of scales. For example, at the farm scale it could be used to schedule farm traffic so that single tracks can be used by a larger number of farm vehicles, reducing issues such as soil compaction and increasing process efficiency, or to automate processes such as grain offloading by synchronising the movements/positioning of multiple vehicles. It could also provide detailed information about variation in environmental conditions which could be interpreted by the machinery which delivers fertiliser, allowing it to be applied in different qualities relative to the existing soil chemistry, with the implied financial and environmental savings. All of these sensing technologies are becoming smaller, more robust, less expensive and more accurate, leading to a data revolution which will reshape the way decisions are made. Coupled with developments in automation, this data revolution could lead to farming with relatively little human labour, such as the experimental '[Hands-Free Hectare](#)' at Harper Adams University.



Robotics, AI, and Advanced Farm Machinery

Central to the process of implementing precision agriculture principles, is the development of the hardware and software that will enable processes to be carried out. Information is only powerful if it is possible to use it to improve a process or task. Robotics represents the field

with the greatest potential to enable automation. A robot is simply any piece of equipment capable of carrying out a task without the need for any human labour. Robots range from static machinery in a factory (e.g. filling sacks/stacking pallets), to limited mobility systems such as robotic milking parlours, all the way through to [AgBots](#), which carry out field-based tasks such as seed sowing, weeding, or herbicide application. There are some [examples of robots](#) either in development or on the market already, although they are not considered mainstream as yet. Manure cleaning robots, operated and/or programmed using a smartphone, collect manure and release water (helping make the manure more liquid and easier to take in), resulting in a cleaner barn floor, improved animal welfare and reduced health and safety risks. An automated strip-grazing system moves electric fence lines using two robots to ensure complete grazing. The robots are powered by solar panels and communicate with one another using Bluetooth. The robots aim to maximise pasture utilisation by moving at a speed that ensures all forage has been consumed. Automated feeding robots are also available, and can be programmed to dispense a range of different feed mixes (milk, silage, hard feed) at pre-set times of day. This can help increase feed intake, improving animal fertility, production, and health in addition to reducing labour. Lastly, weeding robots have also been developed to automate a range of different weeding methods, from harrowing to flaming and freezing. Such robots recognise any weed (using image analysis tools) and navigate their way around the field using sensors and cameras whilst sticking to tyre tracks to avoid damaging crops. A robotic weeder is part of the '[Hands-Free Hectare](#)' experiment at Harper Adams University.



Robots can either gather information themselves using on-board sensors, or be connected to data systems which send them information using mobile information technologies (e.g. 4G/5G mobile networks). The use of robots reduces the overall reliance on human labour, but also allows the redeployment of human labour into tasks which require human intuition and decision making, something which robots cannot yet (and perhaps never will) be able to accomplish. The most advanced robots will be able to gather information as they operate, and compare the data they receive with previous versions, as well as central databases, to 'learn' how to complete a task more efficiently. This type of artificial intelligence (AI) will result in an ever increasing degree of efficiency, and could result in new

methods/approaches to farming based solely on data. The limits of AI, into the future depend entirely on the degree of control we allow. At present, computer learning is based solely on objective criteria, but future systems may be able to more closely mimic human behaviour using AI based learning.

Regardless of their degree of automation, or indeed the use of AI, changes in the design of farm machinery will nevertheless, improve agriculture. Although a human may still be operating a piece of machinery, the tools they will have access to will change the nature of the tasks they are using the machinery for. Modern tractors, for example, already have advanced on-board computers, able to process and apply a range of information from different data sources including GPS, GIS and RS. [Driverless tractors](#), for example, may be fully autonomous or supervised, with a person monitoring vehicles from a central point or with a manned tractor in the lead. In addition to carrying out tasks, autonomous vehicles can carry sensors and cameras, efficiently collecting further data and allowing easy [monitoring of crop health and status](#). Farm vehicles are also fitted (or can be fitted) with a wider range of accessories for completing different tasks, reducing the need for multiple vehicles. This has necessarily made them larger and heavier, leading to the invention of new components such as [high-flex tyres](#), [cleaner/more efficient engines](#) (SGR, EGR etc.), and more [advanced controllers for computational data transfer](#) between devices to ensure compatibility (known in computing as BUS).

Connectivity and the Internet of Things

The ability of systems and devices to operate automatically, robotically, or otherwise will be driven by their ability to communicate with each other, with data repositories, and with control/command centres. Enter 'the internet of things' (IoT). The [IoT](#) describes the (potential) network created by the proliferation and distribution of 'smart' devices. In order to co-ordinate activities, give instructions, or indeed to learn from experiences, all farm-based technology will need to be able to give, receive and process communications effectively. As managers of these devices, future farmers will also need systems to allow them to collate and review data, as well as to initiate activities and tasks. Such command systems are already in development, and are governed by the principle of informed decision making for improved [farm management](#) (e.g. [Agrivi](#) or [BovControl](#)) or collaborative supply chains (e.g. [Farmers Web](#)). In such networks, systems interact with cloud based data repositories to archive, retrieve and compare data. In the future, systems will be able to integrate data collected by a wide range of sensing systems, together with inventory, financial and business planning data, to provide central dashboard services that will keep farmers informed about the state of a large number of aspects of the farm business. This will enable even small scale farmers to decide when and how to apply their time, money, experience and farm labour most effectively. As well as applying to farmers, or farm businesses, the IoT can also be applied to other elements of agriculture, such as individual animals. The number of data points that are available for an individual animal from technologies such as [EID tags/collars](#) (milk yield, vaccination record,

vital statistics, reproductive history, genetic profile *etc.*) will be combined with monitoring technologies such as weighing scales, thermal imaging, and video cameras, and used to inform animal medicine, breeding, herd/flock management and a number of other processes. This is encapsulated in the concept of '[The Connected Cow](#)', but could equally apply to other animals, plants, landscapes, or products.



Electrification

All of the infrastructural components described in the previous section require power. Although many farm vehicles are currently powered by fossil fuel based energy sources, the global trend is to reduce reliance on these sources. That, coupled with the demand from computers, robots, mobile devices *etc.*, means the demand for electricity on the average farm is likely to increase significantly. There is therefore, a mega trend towards electrification, which will have a fundamental effect on agriculture, potentially leading to changes in the structure, distribution, and even size of farm businesses. Electrification can be considered at a range of scales, however, it is primarily a function of the triad of electricity supply, electricity consumption and electricity generation. Electrification will likely be enabled by a range of technologies, encompassing, but not limited to, [micro-generation through renewables](#) (wind, biomass, solar, geothermal, hydro), [regenerative power](#) (where machinery generates its own energy), [district energy](#) networks (collaborative local power sharing) and upgrades to the central energy grid in rural areas. Some examples of innovative electric drive systems have already been revealed such as the [ElectRoGator](#) by AGCO. Tractor manufacturers such as John Deere have also exhibited examples of tractors with crankshaft driven electric generators, suggesting that the fuel savings will soon make hybrid farm vehicles, and fully electric farm vehicles, a reality.

Circular Economy/Energy production

Electrification, and a generally increasing demand for on-farm energy will naturally lead to further consideration of private, or at least highly distributed energy generation. The term micro-generation is mostly used to refer to (comparably) small scale energy generation which is intended to supply a single business, or local area, rather than to contribute *per se* to central demand. Farm businesses will increasingly see the benefit of owning their energy supply, as the cost of deploying renewable technologies such as wind, solar, geothermal, hydro, and biomass continue to decrease, and the cost of traditional energy continues to rise.

Farm businesses are likely to take this principle one-step further, considering (as far as possible) the entirety of the energy flows into, and out of their operations. This would for example, involve developing specific strategies for maximising energy efficiency, reducing/reusing/recycling waste streams, integrating multiple revenue streams and optimising processes. The accrued benefits of adopting this approach are typified in the modern understanding of '[The Circular Economy](#)'. Technologies which will enhance the transition to a circular approach to agriculture, are therefore, likely to have a transformative effect on farm practice. Waste recycling is a good case study in this regard, with the uptake of keystone technologies such as [anaerobic digestion](#) (AD), growing in the UK. The potential to optimise AD for certain farm types, waste streams and desirable products is a growth area in research, and will likely result in farm businesses recirculating resources, and creating value-added products from current waste streams. The [Smart Circle project](#) typifies research in this area, working closely with farm businesses to maximise resource use efficiency.

Central to the ability for individual sites to generate their own energy, or for the national grid to increase reliance on renewables, is the ability of energy storage technologies to provide a means of offsetting variation in production potential (e.g. coping with variation in the number of days of sun in the UK). Energy storage is a rapidly developing field, which in recent years, has seen pioneering companies such as Tesla, find ways to smooth out energy supply when using renewables by harnessing the chemical properties of a range of molecules.

Indoor Vertical Farming

Most specifically relevant to horticulture, indoor vertical farming could be described as the most extreme expression of controlled agriculture. It could feature all the revolutionary elements that have already been discussed, but applies all of it to a different production context. The central tenet is that the most inefficient aspect of plant production is its dependence upon suitable climatological conditions. One way or another, every process that a farm business employs is in response to a challenge posed by the natural environment. The two defining features of an indoor vertical farm are therefore, the stacking of multiple layers of growing space (increasing the amount of growing space per unit land area) and the provision of all of the biological needs of the plants (light, nutrients, water *etc.*) through technological

solutions such as recirculating [hydroponics](#) and [low energy LED's](#). Control is the key benefit of this approach, offering the possibility to fine tune elements of the environment such as the wavelength of light, concentration of nutrients, amounts of water and temperature to provoke the development of desirable characteristics/nutritional components in the crop. This approach is predicated on the scientific literature covering the [responses of plants to stress \(e.g. variation in light\)](#), which is an important driver of nutritional value, but cannot be consistently replicated outdoors. With control comes the potential for high levels of efficiency. Depending on the amount of layers of growing space, a vertical farm could yield many times more produce on the same land area as its outdoor equivalent. It is also possible to have control of the inputs and outputs from the process, and so indoor vertical farming lends itself to being co-located with renewable energy production, and waste recycling technologies. The latter offer the potential to re-circulate nutrients and re-capture heat energy, but also to utilise further waste products such as the CO₂ produced during AD. Critics point out that the process is energy intensive, a problem which is inescapable, but not insurmountable, and requires a heavy capital investment at the outset. Nevertheless, the adoption of elements of the technology (e.g. hydroponics) is widespread, and the development of large scale production facilities continues, driven by the promise of consistent, year round supply, without the need for chemical additives, on a farm which is agnostic of location and highly efficient.



Preventative Medicine

Future agricultural practice will be heavily influenced by the modern recognition that human

and veterinary medicine are closely interrelated, and should be considered in parallel. The [One Health Initiative](#) is a global movement that urges medical practitioners from all disciplines to recognise the links between their practices, and consider their implications on the widest possible field. Central to this are concerns regarding the emergence of an increasing number of [antibiotic resistant microorganisms](#), and the prevalence of [zoonotic diseases](#). Agriculture has been identified globally as a source of antibiotic resistance and zoonotic disease transmission, and as such new legislation has begun to more tightly regulate the use of these drugs amid fears regarding human health, particularly the lack of discoveries of new antibiotic compounds in recent decades. This has led to a focus on preventative medicine, biosecurity, and animal welfare, which is re-shaping animal husbandry practices for farm businesses in many countries. [Next generation vaccines](#) for example, are based on sequences of DNA or RNA which encode for specific antigenic proteins based on a specific pathogen. These sequences are taken up by the vaccinated body, and allow it to acquire its own immunity. Such vaccines are easier to produce at scale, and potentially more effective at preventing disease outbreaks. Alongside the medical interventions, there have also been rapid developments in welfare practices, animal nutrition and environmental management. The technologies used in these areas are also potentially transformative, particularly in the context of the one health initiative. For example, [flush systems](#) are now in use on (mostly) US dairy farms, which use a torrent of water to clean solid barn floors and the filtering power of sand to recycle water. Water is flushed along alleys built on a 2-3% slope, which removes all waste material and cleans the cows' feet. The dirty water then flows down the drain and into a sandpit, where the solid waste matter falls to the bottom and the water is drained for another round of filtering, before being syphoned into a storage tank ready to be used again.

In terms of animal nutrition, a range of feed additives including pre and probiotics, in-feed enzymes, mineral and trace elements additives, and phytochemical (e.g. fatty acid) amelioration have all received [scientific attention](#) in recent years, and are at different stages of integration into practice. Essentially each of these approaches, together with improvements in animal welfare aim to improve general health and resilience in livestock, thus reducing disease incidence. A similar approach can be taken to ameliorate environmental conditions, such as soil health (particularly microbial), to improve the access to nutrients of forage and fodder crops, and consequently the nutritional status of animals.

Biosecurity has also been drawn into sharp focus by health concerns, and forms an integral part of modern farming operations. Combined drivers, including a need to reduce the use of pesticides, herbicides and fungicides, the aforementioned preventative steps in veterinary medicine, and the need to reduce the spread of new pests and diseases in the context of climate change, have provided the impetus for increasingly sophisticated biosecurity measures, which when effectively applied can have quality, logistical and financial benefits. There has been a movement to integrate animal and plant biosecurity, particularly on mixed holdings, and an attempt to re-focus efforts on prevention rather than cure. Both individual farm businesses and governing bodies will need to decide how to allocate resources in terms of biosecurity, between preventative measures, control measures and eradication methods.

This will require farm businesses to conduct relatively sophisticated cost-risk-benefit analyses of different approaches. Arguably, the approach of the last century was to 'build walls' in order to protect, whereas in the increasingly globalised marketplace of the future, the cost of import may continue to fall, and this option will become less feasible, and a more responsive approach may be needed. [A recent review](#) suggested three pillars of future biosecurity; integration of biosecurity measures (e.g. plant and animal), increased international cooperation (e.g. communications, warning systems, and standardised protocols) and increasing resilience and resistance (e.g. breeding for resistance, vaccines, crop diversification).

Genetic Engineering

Farmers have been genetically engineering their livestock for decades, without necessarily knowing it. Selective breeding is the oldest form of engineering, ensuring that only animals with desirable traits are bred to increase the likelihood of these characteristics in the offspring. Now, molecular methods such as genetic testing are available to putatively identify individuals with the desired genetic traits. Genetic evaluation is widely used in conjunction with statistical methods (BLUP) to predict performance values for livestock (fertility, maternal characteristics, weight at slaughter etc.). BLUP values are available for most pure breeds and have contributed significantly to the maintenance of rare and purebred livestock. Through publicly funded schemes in Wales, many farmers have been able to genetically profile their ewes and are now moving to do the same with their breeding rams. Recently, CRISPR has received much attention, a gene-editing tool that enables permanent modification of DNA in living cells. In livestock, this could allow the insertion of disease resistance genes for instance, in one generation, and then through selective breeding create a flock of completely resistant animals, which reduces the need for antibiotics, anti-parasitic drugs and many other veterinary interventions. Other examples include the [Enviropig](#), which is genetically engineered to breakdown the phosphorous contained in its own manure. This technology has been met with resistance from both consumers and animal welfare advocates and public acceptance remains a key issue for this technology. The Canadian bio-technology company, CBAN and BFF, invented the first iteration of the Bio-Pig in 1999, and in 2010 the University of Guelph was granted approval for the reproduction and export of the Enviro-Pig, but faced significant resistance from both consumers and animal activists. The pigs were genetically engineered via gene insertion to produce 30-70% less phosphorous in their faeces, by producing the phytase enzyme in the salivary gland. As of June 2012, all remaining Enviro-Pigs were humanely euthanized after the university announced an end to the research and withdrawal from funders. Whilst the concept of GM animals is technically sound, there are considerable moral and ethical issues to grapple with before anything approaching a mainstream use of these technologies can be realistically contemplated.

Summary

Agriculture 4.0 is here, and it is loaded with challenges, opportunities, and a strong impetus for change. Whilst there is a learning curve, and in some cases, it may be steep, what we are witnessing is the most rapid broadening of the 'farming toolkit' in living memory. It is crucial that access to good advice and support is provided, because when it is, this raft of new technologies can have a dramatic positive effect on rural livelihoods, economies, and the ability of the food supply chain to tackle the grand challenges of our age. With better information, more efficient processes, and the confidence of assured provenance, the agricultural sector will be better equipped to play its part in tackling climate change, nourishing a growing global population, reducing waste, and tackling global health challenges, into the future.

